The TAUVEX UV Imager

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In early 1988 the Israel Space Agency (ISA) solicited academic and commercial research and development groups in Israel to propose scientific payloads for a National Scientific Satellite (NSS). Among the many proposals submitted, that of Tel Aviv University, to orbit a number of small, wide-field telescopes to image astronomical objects in the ultraviolet (UV), was finally selected with the highest priority. This payload is referred to below as the **T**el **A**viv University **UV E**xperiment (TAUVEX).

Since the early 1970's there has not been a space experiment able to image a wide field with reasonable angular resulution in the UV, which operated for more than about 10 days. The only full sky survey in the UV was conducted by the TD-1 satellite and resulted in a catalog containing 31,215 sources measured in four spectral bands. Selected regions, to deeper levels that the TD-1 survey, were observed by telescopes from balloons, rockets, or dedicated satellites. The deepest such partial surveys by wide-field imagers are by the FOCA balloon telescope and by the UIT Shuttle-borne instrument.

Observations in the UV region longward of Lyman α (Ly α) up to the atmospheric transmission limit of ∼3000Å take advantage of the reduced sky background. This is because of a fortuitous combination of zodiacal light decreasing shortward of ∼3000Å and other backgrounds remaining low up to near the geocoronal Ly α. In this spectral region it is therefore possible to observe faint astronomical sources with a high signal-to-noise ratio with a modest telescope (O'Connell 1987).

The sources best studied with small aperture telescopes are QSOs and AGNs, that radiate significantly in the UV. Other sources of UV photons are hot stars of various types, the most interesting being white dwarfs and mixed-type binaries. Young, massive stars, that emit copious amounts of UV radiation and ionize the interstellar medium, are important in the context of star formation and evolution of galaxies; here the advantage of a wide-field imager is obvious. This has been demonstrated amply by the UIT instrument flown on the Space Shuttle (Stecher *et al.* 1992). The obvious advantages of TAUVEX here are reduced sky background, the longer observing time per target, and the long duration mission.

In June 1991 it was proposed that TAUVEX be launched and operated from the Spectrum Röntgen-Gamma (SRG) spacecraft as part of the SODART (Soviet-Danish Röntgen Telescope) experiment. The SRG satellite will be launched in late 1997 by Russia into a high elliptical four-day orbit. SRG is the first of a series of space astronomical observatories being developed under the sponsorship of the Russian Academy of Sciences with financial support of the Russian Space Agency. For SRG, the scientific support comes from the Space Research Institute (IKI)

of the Russian Academy of Sciences, and technical support is given by the Babakin Institute of the Lavotchkin Association.

SODART (Schnopper 1994) consists of two X-ray imaging telescopes, each with four focal-plane instruments, to perform observations in the 0.2-20 keV band. It images a one-degree field of view with arcmin resolution. TAUVEX will provide SODART with aspect reconstruction and will assist SRG in pointing and position keeping. In September 1991 the TAUVEX experiment was officially invited to join other instruments aboard the SRG spacecraft. ISA agreed in November 1991 to provide SRG with the TAUVEX instrument. The official confirmation from the Russian side was received in December 1991.

The TAUVEX imagers will operate on the SRG platform alongside numerous X-ray and γ-ray experiments. This will be the first scientific mission providing simultaneous UV-X-γ observations of celestial objects. The instruments on SRG include, apart from SODART, the JET-X 0.2-10 keV imager with 40' FOV and 10-30" resolution, the MART 4-100 keV coded aperture imager (6° FOV and 6' resolution), the two F-UVITA 700-1000Å imagers (1° FOV and 10" resolution), the MOXE all-sky X-ray burst detector in the 3-12 keV band, and the SPIN all-sky γ-ray burst detector in the 10keV-10MeV band with 0°.5 optical localization.

TAUVEX will be bore-sighted with SODART, JET-X, MART and F-UVITA, and will obtain simultaneous imaging photometry of objects in the UV with three independent telescopes. A combination of various filters will accomodate wide, intermediate and narrow spectral bands. These will be selected to take maximal scientific advantage of the stability of SRG, the image quality of the optics (90% of the energy in ∼8"), and long staring times at each SRG pointing. During a single pointing it will be possible to change filters, thus more than three UV bands can be used on one observation.

The present design of TAUVEX includes three co-aligned 20 cm diameter telescopes in a linear array on the same mounting surface. Each telescope images 54' onto photon-counting position-sensitive detectors with wedge-and-strip anodes. Such detectors are space-qualified and have flown in a number of Space Astronomy missions. The TAUVEX detectors were developed by Delft Electronische Producten (Netherlands) to provide high UV quantum efficiency at high count rates. Most systems within TAUVEX are at least doubly-redundant. The choice of three telescopes with identical optics and detectors adds an intrinsic degree of redundancy. More safeties are designed into the software. Because of SRG telemetry constraints, TAUVEX has to accumulate an image on-board, instead of transmitting time-tagged photons. The drift of the SRG platform is compensated within the payload, by tracking onto a ∼bright ($m_{UV} < 10.5$ mag) star in the field of view. The tracking corrections are used to register the collected events and are supplied to the SRG orientation and stabilization system.

The payload was designed and is assembled by El-Op Electro-Optics Industries, Ltd., of Rehovot, the top electro-optical manufacturer of Israel, with continuous support and supervision of Tel Aviv University astronomers. The development of TAUVEX follows a number of stages, in which the predicted behavior is verified by extensive tests. El-Op already produced a number of models of the experiment that were delivered to the Russian constructors of the spacecraft. The delivered models include a size mockup, a mass and center of gravity model for satellite vibration tests, and a thermal simulation model. The latter, in particular, is identical to the flight model except for its lack of electronics and working detectors. All construction details and surface finishes were included, the telescopes have actual aluminized mirrors, etc.

The thermal model was tested at an ESA (European Space Agency) facility in Germany in late-January 1993 prior to its shippment to Russia. The test was a full space simulation,

including Solar radiation, and the measured behavior verified the theoretical model developed at El-Op. The thermal model has now been installed on a model of the entire spacecraft, which will be submitted to a full environmental test, including shocks and vibrations appropriate for the PROTON-2 launch.

In April 1993 El-Op completed the engineering model of TAUVEX, which contains operational electronics. After testing, this model was shipped to the Russian Space Research Institute in Moscow, where it has been tested intensively. In particular, during 1996 the SRG instrument teams conducted a series of Complex Tests, in which instruments were operated together, as if they were on-board the satellite. Two more such tests are planned, until the engineering models of the instruments are delivered early in 1997 to the Lavotchkin Industries to be integrated in a full spacecraft engineering model. At present, the SRG schedule calls for a launch by the end of 1997.

In parallel with tests in Russia, the TAUVEX models are passing their qualification in Israel. During the first half of 1996 the Qualification Model (identical to the flight model) has been vibrated and submitted to shocks stronger than expected during the SRG launch. In September 1996 we expect to proceed with the thermal-vacuum qualification. This test, which lasts more than one month, checks the behavior of the instrument at extreme temperatures and in high vacuum conditions. During these tests, we project various targets onto the telescopes' apertures with a high-precision 60 cm diameter collimator that allow us to fully illuminate one of the three telescopes. We test for resolution, distortion, photometric integrity, spectral response, etc.

While the QM is being paced through the qualification process, El-Op continues building the flight model (FM). The optical module, containing the three telescopes, has already been built and adjusted. The integration of the detectors and electronics will follow immediately upon the completion of the thermal tests. The FM will be submitted to a burn-in process, a low-level qualification, followed by an extended calibration in the thermal vacuum chamber of El-Op.

The timetable of the SRG project calls for the upper part of the SODART telescopes to be integrated with the X-ray mirrors at IABG, near München, in Germany. TAUVEX, which requires very clean assembly conditions and is connected to a mounting plate on the side of the SODART telescopes, will be integrated at IABG at the same time. Following the integration, the entire top part of the SRG spacecraft will be transported to Russia to be tested at Lavotchkin and integrated with the rest of the scientific payload.

The combination of long observing periods per source offered by of SRG (typically 4 hours, up to 72 hours), and a high orbit with low radiation and solar scattered background, implies that TAUVEX will be able to detect and measure star-like objects of $\sim$20 mag with S/N=10. This corresponds to V$\simeq$22.5 mag QSOs, given typical UV-V colors of QSOs; at least 10 such objects are expected in every TAUVEX field-of-view. During the 3 year guaranteed life of SRG at least 30,000 QSOs will be observed, if the targets will be different and at high galactic latitude. This is $\sim 5\times$ more QSOs than catalogued now. The multi-band observations, combined with ground-based optical observations, allow the simple separation of QSOs from foreground stars.

Diffuse objects, such as nearby large galaxies, will be measured to a surface brightness of $m_{UV} \simeq$20 mag/$\Box$". A survey of the Local Group galaxies and nearby clusters of galaxies, that cannot be conducted with the Hubble Space Telescope because of its narrow field-of-view, will be a high priority item in the target list of TAUVEX. TAUVEX will detect hundreds of faint galaxies in each high latitude field. The large number of galaxies at faint UV magnitudes is indicated by balloon-borne observations of the Marseilles CNRS group (Milliard *et al.* 1992). Recently it became clear that the UV-bright galaxies observed by FOCA may be related to those

responsible for the Butcher-Oemler effect in clusters of galaxies. It is even possible that most faint, high latitude UV sources are galaxies.

Our prediction models indicate that each high-latitude field will contain similar numbers of galaxies and stars. Allowing for a reasonable fraction of low-**b** fields, we estimate that TAUVEX will observe $\sim 10^6$ stars, mostly early type and WDs. The data collection of TAUVEX will represent the deepest UV-magnitude-limited survey of a significant fraction of the sky.

An additional major contribution of our experiment to astrophysics is the unique opportunity to study time-dependent phenomena in all energy ranges, from MeV in the γ-ray band to a few eV in the UV, together with the other scientific instruments on board SRG. The combination of many telescopes observing the same celestial source in a number of spectral bands offers unparalleled oportunities of scientific research. For the first time, it will be possible to study the physics of accretion disks around black holes and neutron stars, from the hard X-rays to near the optical region. Other subjects of study include the inner regions of QSOs and AGNs, where the physics of the accretion phenomenon, probably powering all such sources, are best studied with simultaneous multi-wavelength observations.

In preparation for TAUVEX, the science team at Tel Aviv University is collaborating with the Berkeley Space Astrophysics Group in analyzing the UV images of the FAUST Shuttle-borne imager. The analysis is combined with gound-based observations from the Wise Observatory, to enhance the identification possibilities. In parallel with the hardware development, the Tel Aviv team is studying the physics of UV space sources. A predictor model was developed to calculate the expected number of UV sources to any observation direction. The model tested well against the few existing data bases of UV sources. We are also predicting UV properties of *normal* sources from their known optical properties. This will allow us to detect extraordinary sources, through a comparison of their *predicted* and *measured* UV properties. Finally, we are creating at Tel Aviv University a large and unique data base of UV astronomy, by combining a number of existing data sets obtained by various space missions.

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Homepage: Information on TAUVEX, with pictures, is available at:
http://www.tau.ac.il/~ benny/TAUVEX/.

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